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FORWARD RAPID ROTATION SHIFTWORK IN USAF AIR TRAFFIC CONTROLLERS: SLEEP, ACTIVITY, FATIGUE AND MOOD ANALYSES

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13. ABSTRACT (*Maximum 200 words*)

The purpose of this study was to evaluate the shift-specific sleep, general activity levels, mood and cognitive performance of air traffic controllers (ATCs) working a forward 2-2-2 rapid rotation shift schedule. ATCs recorded their sleep, oral temperature and subjective fatigue levels, took a computerized cognitive performance battery (N=13) and completed the Profile of Mood States questionnaire (POMS)(N=12). Actigraphs were used to objectively monitor general activity levels and score sleep and the restfulness of scored sleep (N=9). Analyses were made on the basis of duty shift, post-shift, day of shift, and duty location. There was significantly more actigraph scored sleep, subjectively reported sleep and subjectively measured fatigue and confusion for the ATCs while they were on-duty on the night-shift. The night-shift was also associated with decreased vigor and general activity levels. Significantly more sleep was reported following the first day on each of the three shifts than following the second. Significantly more sleep was reported and scored by actigraph following the swing-shift than following the day-shift. A comparison group of non ATC day-workers reported more post-shift sleep than the ATCs. The radar approach ATCs reported greater confusion and less vigor than the tower ATCs. Insufficient trials were available for direct performance analysis.

14. SUBJECT TERMS

actigraph, air traffic control, body temperature, circadian rhythms, fatigue, mood, night shift, performance, POMS, shiftwork sleep duration

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ABBREVIATIONS

ANOVA	analyses of variation
ATC	air traffic controller
FAA	Federal Aviation Administration
GAAP	General Activity Analysis Program
NTSB	National Transportation Safety Board
POMS	Profile of Mood States
RAPCON	Radar Approach Control
SAM	School of Aerospace Medicine
USAF	United States Air Force

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INTRODUCTION

Most 24 hour U.S. Air Force (USAF) air traffic control operations use a forward rapid shift rotation schedule which rotates every two days through day, swing and night-shifts and then provides 48 hours off. Each cycle lasts eight days. This schedule has been shown to minimize the chronic desynchronosis associated with slower rotation schedules and theoretically eliminates most of the chronic health problems associated with shiftwork[38,54]. Prior studies have shown that the rapid rotation maintains the workers' circadian rhythms in a diurnal orientation[10,12,13,22,29,30]. However, on the night-shift, rapid rotation shiftworkers must operate at the nadir of their diurnally oriented circadian rhythms. This leads to some concern when this schedule is used in safety critical operations such as air traffic control. Studies measuring speed, accuracy, vigilance and lapses in attention in non-air traffic controllers have consistently shown performance to be worse during the night hours[9,27,37,39,44]. In a classic study in 1955, Bjerner performed a retrospective study of meticulously tracked ledger error rates for shift workers at a Swedish gasworks from 1901-1943. This study showed a consistent, significant nocturnal peak in error rates[5]. A performance trough in the early morning hours has been implicated as contributing to the Chernobyl and Three-Mile Island nuclear reactor incidents[17], the Bhopal chemical release[20], the grounding of the Exxon Valdez[52], and the Space Shuttle Challenger accident[36]. Following the Three-Mile Island incident, Ehret commented on the possibility of using a rapid rotation shift in the nuclear energy industry:

> ...[a rapid rotation shift schedule] may be most desirable in a large number of relatively noncritical or low hazard enterprises. However, for plant operators, and for other individuals with critical decisions to make, we find this method unacceptable because it discourages phase shifts... results contribute to performance deficits in the very early morning hours.[17]

Ultra-slow shift rotations and permanent shifts can maximize night-shift capabilities by entraining a nocturnal circadian orientation. However, because of the low night-shift workload at most USAF air traffic control operations, slow rotation schedules would adversely affect air traffic controller (ATC) proficiency[51].

The purpose of this study was to evaluate the shift-specific sleep, general activity levels, mood and cognitive performance of air traffic controllers working a forward rapid rotation shift schedule.

METHODS

This study was conducted in August and September 1992 at Loring AFB, Maine. The ATCs' shift rotation schedule was not disrupted or altered; the ATCs continued to work their normal duties on their usual schedule at their normal duty location. The three week period of the study covered two and a half shift rotation cycles. Out of a total of 43 ATCs available, 32 (74%) worked the rapid rotation schedule. The remaining 11 (26%) worked straight day-shifts in administrative or training positions or worked irregular hours as "floaters" - filling in on various shifts on an as-needed basis. The rapid rotation controllers were all enlisted personnel ranging in rank from Airman to Master Sergeant. Fourteen of the ATCs were originally selected for the study based on the following two criteria: they were rapid rotation shiftworkers and they were present for the duration of the study. Nine ATCs were from the Radar Approach Control (RAPCON); five were from the Control Tower (Tower). Twelve of the 14 ATCs worked the standard 2-2-2 forward rapid rotation shift schedule. This schedule consists of working two day-shifts, two swing-shifts and then two night-shifts. Following the second night-shift the ATCs are given 48 hours off before beginning the cycle once again. Each shift was eight hours in length. Shift changes were at 0700, 1500, and 2300 (Fig.1). Naps were permitted during break time provided by the watch supervisor on duty. These breaks were granted depending on available manning and workload. They generally lasted less than 30 minutes on each shift. Two of the five Tower ATCs worked a "super rapid rotation" of 1-1-1. On this schedule they worked one day-shift, one swing-shift, one night-shift and then had 48 hours off before beginning the cycle again. The results from the two ATCs working the 1-1-1 rotation were not found to differ from those of the 2-2-2 ATCs and were therefore included in all analyses.

The ATCs routinely report the number of aircraft contacts by duty position for specified six hour periods. The number of contacts are averaged for three month blocks of time. The average number of contacts by duty position for these ATCs for the three month period which included this study provides a reasonable measure of workload. Workload was light to moderate on the day and swing-shifts and very light on the night-shift (Table I).

Study Group. All the ATCs in the study group were male except for one RAPCON ATC. The mood data from the lone female ATC and one Tower ATC were incomplete and not usable; their data were used only for the sleep and fatigue log and performance parts of the study. One RAPCON ATC participated only in the POMS portion of the study. The study group's military rank ranged from airman (E2) to technical sergeant (E6). The mean rank was senior airman (E4). ATC experience ranged from 0.5 years to 15 years. The ATCs participating in the actigraph portion of the study had a mean rank of senior airman (E4); their experience ranged from 0.5 to 5 years. The Tower ATCs were of slightly higher rank on average than the RAPCON ATCs (Table II).

Comparison Group. A group of eight healthcare technician day-workers was used to compare amounts of subjective sleep and mood. This comparison group was evenly split between males and females. Their average rank was senior airman and their average age was 29.5. They were dental, pediatric, aerospace medicine, and administrative technicians. This group was selected because they were accessible standard diurnal workers with a rank profile (Table III), duty activity levels and off-duty life styles similar to the ATCs.

Logs. (N=13) Each ATC in the study maintained a subjective sleep log for the duration of the study. They noted all sleep - including naps - which occurred on or off-duty. The most common periods for off-duty sleep were identified in one hour blocks of time when the ATCs averaged more than 30 minutes of reported sleep. All ATCs were given oral thermometers (Model #2860, Becton Dickinson Inc., Franklin Lakes, NJ) and recorded their temperature every four hours while awake for the duration of the study. The subjects' temperatures were plotted against time to verify diurnal oral temperature circadian rhythms. With each temperature they also subjectively rated their fatigue using the 7-point School of Aerospace Medicine (SAM) Fatigue Scale[50]. Mean fatigue scores were obtained for each duty shift.

Actigraphs. (N=9) Small, computerized, wrist-worn activity monitors (actigraphs; AMA Model #32, Ambulatory Monitoring Inc., Ardsley, NY) were worn at all times (except while bathing) to objectively measure general activity levels and score sleep. Actigraphs have been found to correctly identify sleep with a high correlation to electroencephalographic measurements[8,43]. The General Activity Analysis Program (GAAP) algorithm designed by Dr. Elmore of the Office of Military Performance Assessment Technology was used to score actigraph sleep (Walter Reed Army Institute of Research, Washington, DC)[18]. Only actigraph scored sleep intervals of 10 minutes or longer were included for analysis in order to ensure a conservative estimate of sleep versus inactivity. Due to a limited supply, only five of the eight RAPCON ATCs but all four Tower ATCs wore actigraphs. Some difficulties were encountered with the actigraphs, such as short battery life, and some data were unfortunately lost due to these problems.

Subjective sleep, actigraph scored sleep, and general activity levels were analyzed and compared across duty shifts, post-shifts, days of shift (first or second), and duty locations. General activity levels during scored sleep were compared for each post-shift off-duty period as a measure of sleep restfulness[43]. Restfulness was measured in activity counts per minute for each hour when scored sleep exceeded 10 minutes. We used Brown's range of normal values for restfulness (7 to 35 activity counts/minute)[7]. Subjective fatigue was evaluated by duty shift, day of shift, and duty location.

POMS. (N=12) Subjective mood was measured at the midpoint of each duty shift through use of the Profile of Mood States (POMS) questionnaire. The POMS consists of 65 adjectives which are rated on a five-point scale that ranges from "not at all" to "extremely". The POMS measures six mood dimensions: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment[33]. Raw and standardized t-scores were compiled for the six mood dimensions. The standardized t-scores were used for all ATC analyses since the t-scores were originally derived from a male population[33] and all ATCs with complete POMS data in the present study were male. The range of possible POMS t-scores is 1 to 70 overall on each of the six dimensions. Comparisons were made along all six dimensions for variation due to duty shift, day of shift, and duty location. Raw scores were used for the comparison group analysis due to the inclusion of women in that group.

Performance Test. At the midpoint of each duty shift the ATCs completed the NovaScan™ "B" computerized performance test (Nova Technology, Inc., Calabasas, CA). This test is appropriate for air traffic controllers because it measures (1) spatial visualization

through an image rotation task, (2) tracking through a random tracking task, and (3) attention allocation through a dial task. The dial task requires the controller to share focal attention and "background" attention. Rapid shifting of attention and resources is required (up to two shifts per second); this provides an intense measure of the attention allocation resource. Response time (msec) and response accuracy (% correct) are automatically recorded by the computer. Over one hundred variables may be measured by this test in one testing session[42]. Twelve variables most specific for air traffic controller performance were used for our analysis. Each individual testing session lasted approximately 10 minutes. The ATCs were unable to obtain sufficient trials on the performance test to get beyond a clear learning curve during the period of this study. Therefore, direct performance analysis was not possible. However analysis of learning on the three duty shifts was conducted.

Analyses. Statistical analyses were accomplished through within-group analyses of variation (ANOVA). Duncan and Scheffe post-hoc ANOVA evaluations were used. Duncan and Scheffe interpretations were in agreement except where otherwise noted.

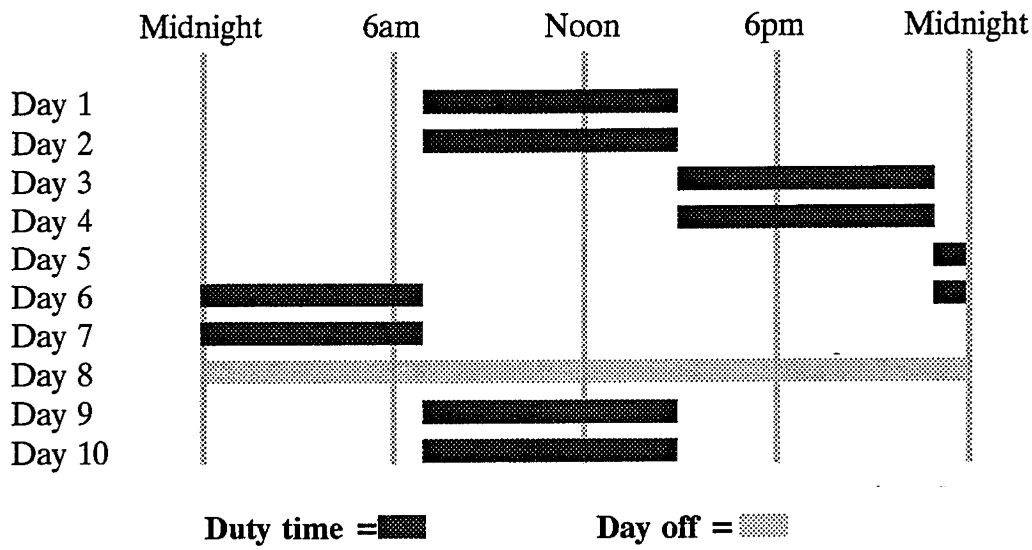

Fig. 1. Ten days of a forward 2-2-2 rapid shift rotation schedule.

TABLE I. AVERAGE WORKLOAD BY
DUTY POSITION AND TIME.

	Position	
	TOWER	RAPCON
midnight - 6 am	15.7	9.2
6 am - noon	33.7	26.6
noon - 6 pm	62.0	40.3
6 pm - midnight	14.9	14.9

Note: unit of measure = aircraft contacts.

TABLE II. ALL ATCs BY RANK.

RAPCON = ■ RAPCON Female = ●
Tower = ○

	Logs	POMS	Actigraphs
Airman (E2)	■	■	■
Airman First Class (E3)	■■■ ○	■■■ ○	■■ ○
Senior Airman (E4)	●■ ○	■■ ○	■ ○
Staff Sergeant (E5)	■ ○○○	■ ○○	■ ○○
Technical Sergeant (E6)	■	■	

TABLE III. ALL COMPARISON GROUP MEMBERS BY RANK.

Comparison group member = ♦

Airman (E2)	♦♦
Airman First Class (E3)	♦
Senior Airman (E4)	♦♦♦
Staff Sergeant (E5)	♦♦

RESULTS

Subjective Sleep. The ATCs reported an average of 26 minutes of sleep during their night-shifts. This was significantly more sleep than was reported during either the day or swing-shifts (p=0.009)(Table IV). Only two of the 13 ATCs participating in this part of the study reported that they never slept on any of the night-shifts monitored. Significantly more subjectively reported sleep was obtained in the off-duty sleep period following the swing-shift than following the day-shift (p=0.010)(Table V). The comparison group averaged 7.94 hours of reported sleep on each night following a duty day; this was greater than the amount of sleep reported by the ATCs following any of their three shifts. There was no difference in subjectively reported sleep between the first and second days on each duty shift but sleep occurring in the off-duty period following the first day on the shift was significantly greater than that occurring following the second day on the shift (p=0.046). Identification of the most common sleep periods indicates that post-day-shift and post-swing-shift sleep periods have more than five hours of overlap (0100 - 0600) and the longest sleep period follows the second day-shift (Table VI).

Scored Sleep. The actigraphs indicated that the ATCs slept for an average of 85 minutes while on duty during their night-shifts. This was significantly more scored sleep than was objectively scored on either the day or swing-shifts (p=0.038)(Table IV). Only one of the nine ATCs wearing actigraphs had no significant scored sleep on any of his night-shifts. Significantly more objectively scored sleep was obtained in the off-duty period following the swing-shift than following the day-shift (p=0.021)(Table V). There was no difference in objectively scored sleep between the first and second days on each shift or post-shift.

Sleep Restfulness and General Activity Levels. The scored sleep obtained in the off-duty time following the day-shift was significantly less restful (p=0.027) than scored sleep obtained following the swing or night-shifts (Duncan interpretation)(Table VII). The more conservative Scheffe interpretation indicated that the post-day-shift scored sleep was less restful than post-night-shift scored sleep but not post-swing-shift scored sleep. General activity levels on duty on the night-shift were significantly less (p=0.017) than general activity levels on the day and swing-shifts (Duncan interpretation). General activity levels on the night-shift were significantly less than general activity levels on the day-shift but not the swing-shift by the Scheffe interpretation (Table VIII). There was no significant difference in general activity levels while awake on duty between the first and second days on each shift (Table IX).

POMS. On the POMS the ATCs reported significantly increased fatigue (p<0.001), confusion (p=0.003), and decreased vigor (p=0.039) on the night-shift when compared to the day or swing-shifts (Table X). No significant differences were found for anger, tension, or depression. The SAM Fatigue Scale data also demonstrated significantly increased fatigue on the night-shift when compared to the day and swing-shifts (p=0.0001)(Table XI). No differences were found along any of the six POMS dimensions between the first and second days on each shift (Table XII). The RAPCON ATCs reported greater confusion (p=0.019) and less vigor (p=0.002) than the tower ATCs. There were no significant differences along the other four POMS dimensions (Table XIII).

The comparison group reported no statistically significant differences along any of the POMS dimensions by day of the week. However, when graphed, the comparison group's

POMS data reveals a clear Wednesday/Thursday "hump" which is consistent along all six POMS dimensions (Fig. 2). Tension, anger, confusion and depression peak on Wednesday. The greatest fatigue and least vigor appears to occur on Thursday.

Cognitive Performance. Performance data indicated a tendency for initial learning on the night-shift to be impaired relative to learning on the day or swing-shifts (Fig. 3) but this difference was not statistically significant. Insufficient trials were obtained for direct performance analysis.

Oral Temperature. This group of rapid rotation ATCs maintained a diurnally oriented oral temperature circadian rhythm irrespective of shift (Fig. 4).

TABLE IV. MEAN OBJECTIVE (ACTIGRAPH) SLEEP AND SUBJECTIVE (LOG) SLEEP *DURING* EACH DUTY SHIFT.

	SHIFT		
	DAY	SWING	NIGHT
OBJECTIVE SLEEP [minutes]	35.5 (16.67)	34.5 (24.68)	*85.2 (69.2)
SUBJECTIVE SLEEP [minutes]	3.9 (9.93)	3.3 (7.39)	**26.3 (24.59)

*p=0.038, night>day and swing **p=0.009, night>day and swing
Note: standard deviations are in parentheses.

TABLE V. MEAN OBJECTIVE (ACTIGRAPH) SLEEP AND SUBJECTIVE (LOG) SLEEP *FOLLOWING* EACH DUTY SHIFT.

	POST-SHIFT		
	DAY	SWING	NIGHT
OBJECTIVE SLEEP [hours]	2.7 (1.2)	*4.7 (1.5)	3.6 (1.3)
SUBJECTIVE SLEEP [hours]	5.4 (1.2)	**7.6 (2.1)	6.3 (2.0)

*p=0.02, swing>day **p=0.01, swing>day
Note: standard deviations are in parentheses.

TABLE VI. OFF-DUTY SLEEP PERIODS.

	SLEEP PERIOD
after the FIRST DAY-SHIFT	2300 - 0600
after the SECOND DAY-SHIFT	2400 - 1100
after the FIRST SWING-SHIFT	0100 - 1000
after the SECOND SWING-SHIFT	0100 - 0900
after the FIRST NIGHT-SHIFT	0700 - 1300
after the SECOND NIGHT-SHIFT	0700 - 1200 and 2400 - 0700+

note: only one hour blocks with >30 minutes average of reported sleep are included.

TABLE VII. RESTFULNESS OF SLEEP OBTAINED FOLLOWING DUTY SHIFTS.

	POST-SHIFT		
	DAY	SWING	NIGHT
ACTIVITY COUNTS/MINUTE	*45.8 (28.9)	26.9 (6.4)	25.2 (5.5)

*p=0.027, day>swing and night (Duncan interpretation)
day>night (Scheffe interpretation)

Note: standard deviations are in parentheses.

TABLE VIII. GENERAL ACTIVITY BY DUTY SHIFT.

	SHIFT		
	DAY	SWING	NIGHT
ACTIVITY COUNTS	5708 (3190)	4965 (1030)	*3403 (1367)

*p=0.017, night<day or swing (Duncan interpretation)
night<day (Scheffe interpretation)

Note: units = activity counts/hour. Standard deviations are in parentheses.

TABLE IX. GENERAL ACTIVITY BY DAY OF SHIFT.

	SHIFT		
	DAY	SWING	NIGHT
FIRST DAY OF SHIFT	5321 (2444)	4869 (1151)	3538 (1241)
SECOND DAY OF SHIFT	6377 (4242)	5128 (801)	1669 (1669)

Note: units = activity counts/hour. Standard deviations are in parentheses.

TABLE X. POMS MOOD DIMENSIONS BY DUTY SHIFT.

	SHIFT				SHIFT		
	DAY	SWING	NIGHT		DAY	SWING	NIGHT
Fatigue/ Inertia	40.9 (8.2)	40.2 (6.0)	*48.4 (7.8)	Tension/ Anxiety	38.2 (4.0)	38.0 (4.0)	38.8 (4.9)
Confusion/ Bewilderment	34.7 (3.2)	35.2 (3.4)	**38.3 (5.8)	Depression/ Dejection	39.7 (2.9)	40.6 (4.3)	40.3 (3.5)
Vigor/ Activity	48.8 (9.4)	50.2 (10.1)	***41.0 (10.8)	Anger/ Hostility	42.0 (9.9)	43.4 (10.4)	42.4 (7.8)

*p<0.001, night>day and swing
**p=0.003, night>day and swing
***p=0.039, night<day and swing

Note: standard deviations are in parentheses.

TABLE XI. MEAN SAM FATIGUE SCALE SCORES BY DUTY SHIFT.

	SHIFT		
	DAY	SWING	NIGHT
FATIGUE SCORE	2.7 (0.9)	2.8 (0.7)	*3.8 (0.9)

*p<0.0001, night>day and swing

Note: standard deviations are in parentheses.

TABLE XII. POMS MOOD DIMENSIONS BY DAY OF SHIFT.

	DAY-SHIFT		SWING-SHIFT		NIGHT-SHIFT	
Day of Shift	First	Second	First	Second	First	Second
Fatigue/ Inertia	40.0 (8.3)	42.1 (8.1)	40.1 (5.0)	40.3 (7.0)	48.4 (7.6)	48.4 (8.4)
Confusion/ Bewilderment	34.9 (3.6)	34.4 (2.6)	35.6 (3.2)	34.9 (3.5)	38.2 (5.4)	38.3 (6.6)
Vigor/ Activity	50.6 (9.9)	46.2 (8.5)	49.1 (10.4)	51.5 (9.9)	40.5 (10.2)	41.7 (12.0)
Tension/ Anxiety	38.8 (4.3)	37.3 (3.5)	38.0 (3.3)	38.0 (4.8)	38.7 (4.5)	39.0 (5.6)
Depression/ Dejection	39.4 (2.5)	40.0 (3.4)	40.5 (4.4)	40.8 (4.2)	40.6 (3.4)	39.9 (3.6)
Anger/ Hostility	40.6 (6.8)	44.1 (13.1)	42.0 (7.6)	44.9 (12.9)	42.7 (7.9)	41.9 (7.8)

Note: standard deviations are in parentheses.

TABLE XIII. POMS MOOD DIMENSIONS BY DUTY POSITION.

	POSITION			POSITION	
	RAPCON	Tower		RAPCON	Tower
Fatigue/ Inertia	43.8 (7.4)	40.6 (5.1)	Tension/ Anxiety	38.6 (3.5)	36.6 (3.0)
Confusion/ Bewilderment	*36.8 (3.6)	33.1 (2.1)	Depression/ Dejection	40.1 (2.6)	39.4 (2.7)
Vigor/ Activity	**44.4 (8.8)	58.9 (7.5)	Anger/ Hostility	43.6 (8.6)	39.9 (3.3)

*p=0.019, RAPCON>Tower
**p=0.002, RAPCON<Tower

Note: standard deviations are in parentheses.

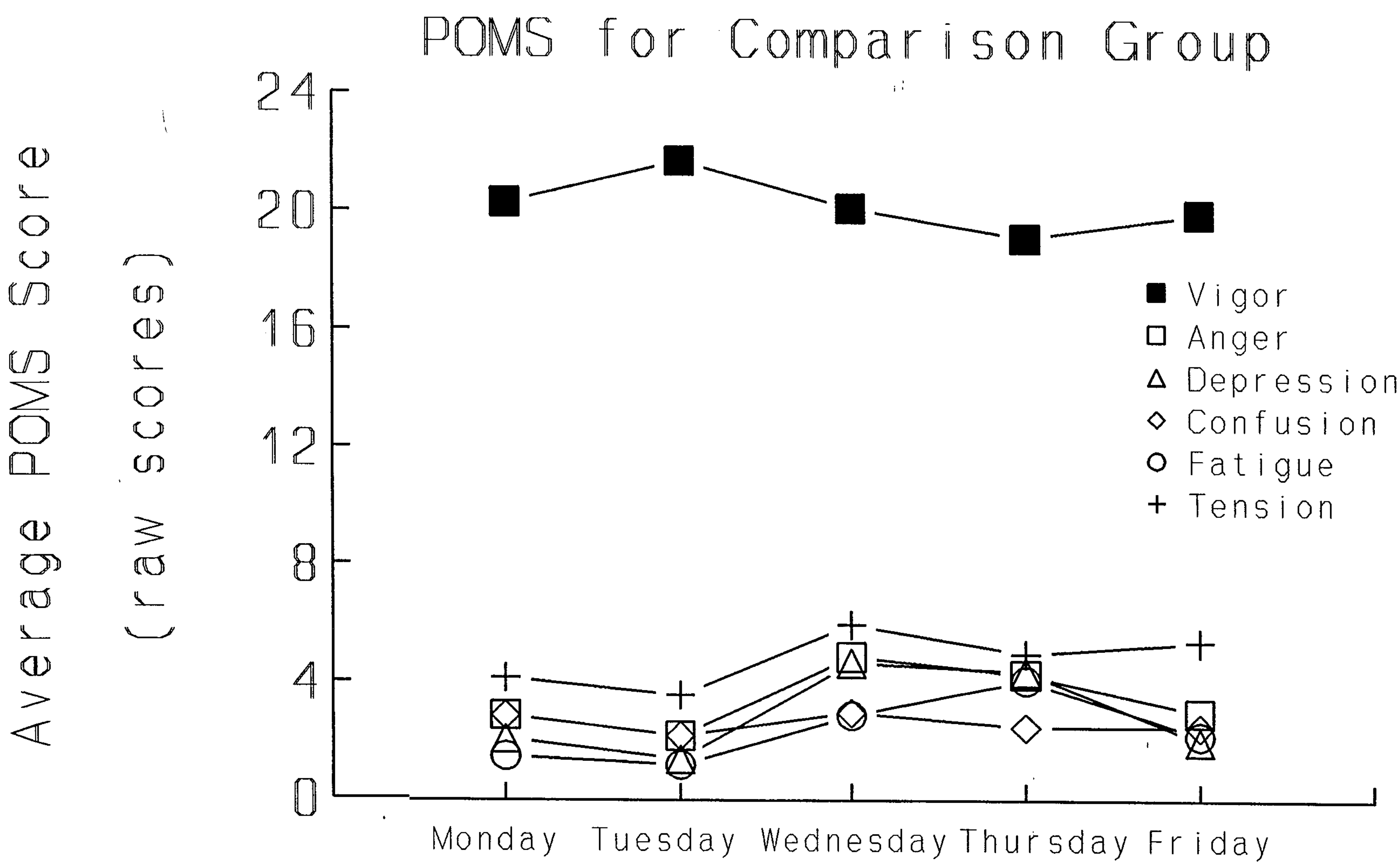

Fig. 2. The comparison group's POMS scores demonstrate an apparent Wednesday/Thursday "hump". This was not statistically significant.

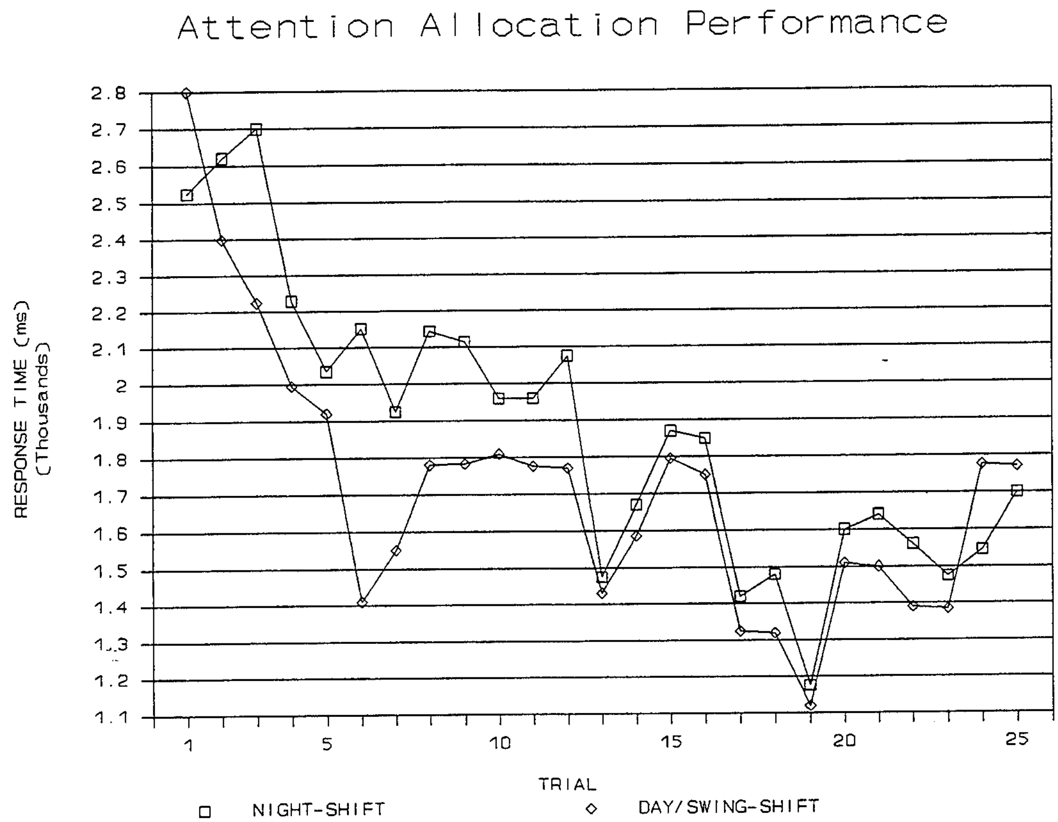

Fig. 3. Day and swing-shift data were very similar and were thus combined and compared with night-shift data. Night-shift attention allocation task learning was not found to be different from the day and swing-shifts.

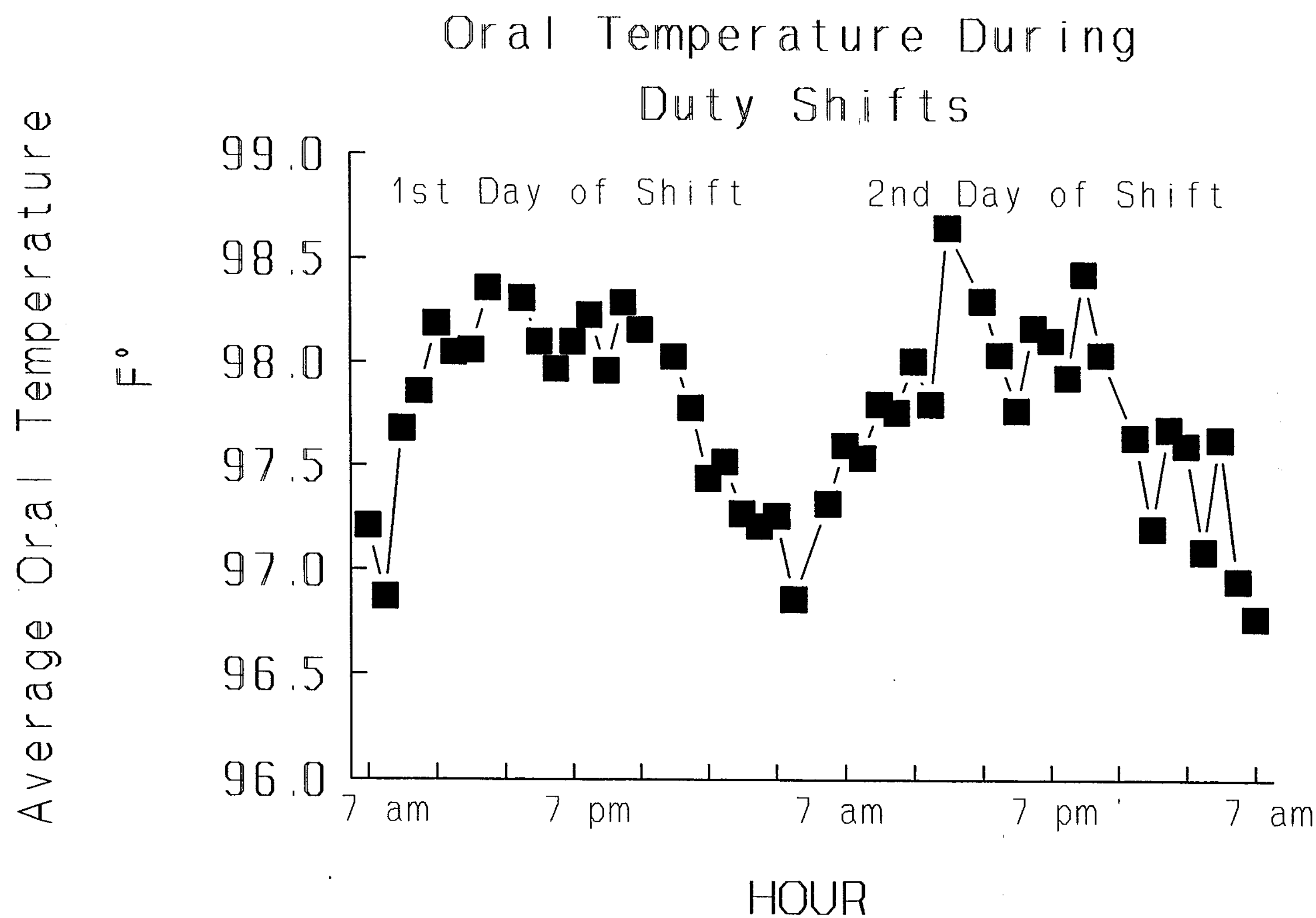

Fig. 4. Composite graphing of oral temperatures taken on duty shifts reveals a sinusoidal circadian pattern.

DISCUSSION

Our ATC data re-affirmed the results of prior studies of rapid rotation shiftwork; diurnally oriented circadian rhythms were maintained despite shift rotation. As in most prior studies, the representative circadian rhythm was the oral temperature rhythm. Maintenance of a diurnal orientation implies that ATCs working the night-shift were operating at the nocturnal trough of their circadian rhythms. Any deleterious effects of this would be expected to be compounded by the facts that they perform their duties in a dark environment and have little to mentally stimulate them due to the low workload levels during the night-shift. Indeed, the POMS demonstrated that the ATCs felt more fatigue, less vigor, and more confused on the night-shift. The SAM Fatigue Scale confirmed the POMS fatigue data. The actigraphs revealed that general activity levels were lowest on the night-shift. More dramatic was the actigraph finding that the ATCs averaged 85 minutes of scored sleep while on duty during the night-shift. This was despite the elimination of all actigraph scored sleep of less than 10 minutes to ensure a conservative estimate of sleep versus inactivity. Both the subjective and objective measures indicated that the ATCs slept significantly more while on the night-shift than on the swing or day-shifts. The subjective sleep values were consistently less than the objective ones and may represent some reluctance on the part of the ATCs to admit falling asleep on duty. In fact, the 26 minute average of subjectively reported sleep during the night-shift could easily have been obtained during typical break periods. The raw data indicated an extreme example of an ATC who was granted an unusually long break of two and a half hours. He subjectively reported a 2.5 hour nap. His actigraph provided a typically conservative scored sleep measurement of 2.05 hours. It is apparent that the subjective sleep data describes legitimate naps obtained during break times while the actigraph data likely provide a conservative estimate of total sleep during the duty shift.

It is important to note that actigraphs do not directly measure sleep; rather, they measure activity. Actigraph scored sleep is most confidently a measure of profound inactivity, albeit one with a high correlation with electroencephalographically determined sleep[8,43]. This study was not designed to directly assess if the ATCs were falling asleep on duty.

The subjective measures of sleep during post-duty periods were consistently greater than the objective values. This may indicate that the ATCs were recording subjectively how much time they were spending in bed while the actigraphs were objectively estimating how much time the ATCs were actually sleeping. The ATCs slept significantly longer following the swing-shift than following the day-shift; this is not surprising. Shiftworkers tend to go to sleep at about the same time whether it is after a day-shift or after a swing-shift. The ATCs could sleep in during the mornings following either of the swing-shifts or the second of the day-shifts - they didn't need to report for duty until later in the day. In the morning following the first day-shift, however, the ATCs had to arise relatively earlier in order to work the second day-shift (Table VI). Therefore, less sleep was obtained following the day-shift relative to the period following the swing-shift. This also explains why more sleep was obtained following the second day on shift than after the first. Overall, the comparison group mean of 7.9 hours of reported sleep was similar to the ATC post-swing-shift subjective sleep mean of 7.6 hours but considerably greater than the ATC subjective sleep following the day and night-shifts. This would seem to indicate a possible overall sleep deficit for the ATCs but this was not directly assessed by this study.

The day-sleep following a night-shift would be expected to be less restful than sleep obtained during the night following the day and swing-shifts but our data indicate that the scored sleep obtained following the night-shift was not significantly less restful than the scored sleep obtained following the swing-shift. In fact the restfulness of the scored sleep obtained during both of these two post-duty periods lies within the generally accepted range of normals[7]. Apparently these ATCs were able to maximize their day-sleep hygiene. Perhaps more surprising was the finding that scored sleep following the day-shift was the least restful and was outside the normal range. Review of the raw data indicate that this is apparently an artifact from the way restfulness was calculated. The ATCs tended to both exercise and nap in the afternoons following their day-shifts. Restfulness was calculated for any hour following the duty shift with scored sleep greater than 10 minutes. In the vast majority of cases the minutes of scored sleep per hour was close to 60 and the activity counts over that hour provided an accurate estimate of restfulness. The afternoon naps often occupied only 15 or 20 minutes within an hour; the remaining 40 or 45 minutes of non-sleep activity artificially increased the restfulness measure of activity counts per hour. This also explains the large variability in restfulness values for this post-duty sleep period. We were unfortunately unable to go back and restrict our restfulness analyses to each minute of scored sleep rather than to each hour of scored sleep. Also, since we restricted our delineation of the most common sleep periods to hours with more than an a mean of 30 minutes of reported sleep, these afternoon naps are not included in Table VI.

Brown's 1990 actigraphy study[7] reports average awake general activity levels of 11100 - 14700 counts/hour. These counts are considerably higher than those demonstrated by the ATCs in the present study. The disparity is likely due to differences in the measurement period and the underlying populations. Brown's group included light industry workers, college students and secretaries ranging in age from 18 to 65 years old. Their activity was calculated for their entire waking period to include recreational activities. Our ATCs have a relatively sedentary occupation and only on-duty activity was included in our calculations. The significant amount of scored sleep the ATCs were receiving on the night-shift also served to lower the activity counts.

It is unclear why the RAPCON ATCs reported greater confusion and less vigor than the tower ATCs. The differences were consistent across shifts. Most likely this was due to selection factors such as the slightly higher experience level of the tower ATCs.

It was interesting to see a clear, if not quite significant, Wednesday/Thursday "hump" in the comparison group's POMS data. Perhaps a larger sample would satisfactorily demonstrate the existence of the popularly recognized mid-workweek "hump".

Our data indicate that ATCs on the night-shift are at least somewhat fatigued with lower vigor and increased confusion and possibly could be falling asleep on duty. This may be concerning but only if impaired duty performance can be demonstrated. Unfortunately, we were unable to obtain sufficient trials on our performance test during this study to get beyond the learning phase. Further study of ATC night-shift performance is clearly indicated.

Search of the National Transportation Safety Board (NTSB) database demonstrates that ATC related incidents and accidents do occur. Over the eight year period from March 1985 to December 1992 in the U.S.A., civilian aviation incidents and accidents with Federal Aviation Administration (FAA) ATCs as a factor involved 77 aircraft and 3770 individuals

(pilots and passengers). Thirty seven aircraft were damaged or destroyed and 279 persons were killed or injured[41]. Shift-specific rates would shed light on the real world impact of the FAA ATCs similar rapid rotation shiftwork schedule but these rates are not currently available. Note, however, that the FAA ATCs schedule is a backward rotation. Direct comparisons of forward and backward rotations are few and the overall performance differences are unknown.

Possible Interventions

If significantly degraded night-shift performance is identified in U.S. Air Force ATCs working a rapid rotation shift schedule, what can be done to improve their night-shift performance? The degraded performance would most likely be due to sleepiness and/or operating at the nadir of their circadian performance curve[21]. Interventions would have to address both these areas.

The goal of using the rapid rotation shift schedule is to maintain the circadian rhythms in a diurnal pattern with the understanding that night-shift performance will probably be compromised[10,52]. Performance will be at the trough even if there is no sleep deficit[3]. In order to operate closer to the peak of their performance curve, the controllers would need to either change their rotation schedule or manipulate their circadian rhythms through an experimental strategy.

At many U.S. Air Force bases, air traffic control operations are needed 24 hours a day but at night there is a much lower work load relative to the day and swing-shifts[51]. The ATCs complain that their performance and confidence begin to deteriorate after being away for as little as five or six days from moderate traffic patterns. Night-shift traffic is not enough to maintain their proficiency. Allowing their circadian rhythms to adapt through slower rotations or permanent night-shifts is therefore not an desirable[51].

Controlled bright light exposure has been well established in animal studies and, more recently, in human studies, as a powerful resynchronizer of circadian rhythms[3,14,15,16,28,31]. Bright light in the evening phase delays the circadian rhythms of diurnal individuals; bright light in the morning advances them[3,14]. With regard to the temperature rhythm, the more closely timed the light exposure is to the rhythm nadir the greater the phase adjustment[14]. Exposing ATCs to bright light would make it very difficult for them to read their radar screens in the radar approach control (RAPCON) or maintain their night vision in the control tower[51]. Also, if bright light was used to delay the circadian rhythms in the evening, daylight in the morning would advance the circadian rhythms and cancel the effect[14,46]. Desynchronosis would result.

Recent initial human studies have shown that exogenously supplied melatonin also holds significant promise as a resynchronizer[2,3,4,10,19,32]. Melatonin administered in the morning immediately following the night-shift would delay the circadian rhythms[32] but this effect is also likely to be canceled through the influence of daylight. If the controllers could somehow make it home and into bed in the morning without being exposed to daylight (blindfolded), the cancellation effect could be avoided but the desynchronosis would still occur once the controllers returned to the day or swing-shift. In general, through their activities as circadian rhythm resynchronizers, both bright light and melatonin counteract the fundamental reasons for using rapid rotation shift schedules.

Several strategies may be tried to improve night-shift performance[49] despite use of

the rapid rotation schedule and operating at the nadir of the circadian performance curve. The work environment should be kept cool. Cool temperatures promote alertness[1]. Tasty, nutritious food should be encouraged and readily available on all shifts. All too often night-shift workers are forced to rely on candy machines, soft drinks and sub-optimal boxed meals[61]. During the long, slow periods ATCs should be encouraged to engage each other in stimulating games or conversation[1].

There have been relatively few studies analyzing the effects of napping on shiftworkers working 8-12 hours a day[23]. In 1989 Härma performed a non-randomized worksite study of women working an irregular shift rotation. He showed that nappers were significantly more alert on the night-shift than non-nappers[24]. Self-selection could have been a large factor, however. Also in 1989, Rogers performed a laboratory study of six women which showed a mild beneficial effect on auditory vigilance and a digit symbol substitution performance test from a one hour nap; however, most performance tasks remained impaired at night[45]. There is a general consensus, however that naps in the early evening should increase alertness and may benefit performance on the night-shift[40,46]. Minors and Waterhouse have reported that naps that are at least four hours long and are taken regularly help "anchor" the diurnal circadian rhythms of shiftworkers[34,35]. However, these naps would be very difficult to schedule for rapidly rotating shiftworkers.

In 1988 Härma studied the effect of physical conditioning on female nurse volunteers working irregularly rotating shifts. They were compared with a well-matched control group. Physical conditioning was found to decrease subjective fatigue and increase subjective alertness on the night-shift[25,26]. These studies concerned off-duty exercise. Exercise during the duty shift may also be of benefit - particularly on the night-shift. A stationary bicycle or rowing machine can generally be set up even in cramped worksites. If controllers can be allowed an hour to leave the worksite near the middle of the shift and can obtain access to a gym, that could be more beneficial.

In limited studies, caffeine has been found to improve night-shift performance[6,45,47]. It must be used early in the shift, however, to avoid affecting daytime sleep. Short acting benzodiazepines, such as triazolam, have shown some promise in improving day-time sleep for shiftworkers without sedation during waking hours[48,53]. However, a study of triazolam-aided daytime sleep across five consecutive night-shifts performed by Walsh in 1988 showed no significant beneficial reduction in sleep tendency or improvement in vigilance in the early morning hours[53].

Day-sleep following night-shifts should be in a comfortable, quiet environment without interruptions. Many USAF ATCs live in dormitories. Whenever possible, they should be given private rooms or roommates who work the same schedule. If possible, a dormitory should be set aside just for shiftworkers.

Lessening night-shift hours may have a beneficial effect on performance[1]. Decreasing night-shift length while increasing day and/or swing-shift length could realize this goal. If the day or swing-shift were ten hours, the night-shift would be only six hours. If both the day and swing-shift were ten hours, the night-shift would be only four hours. Performance might improve on the shorter night-shift despite continuing to work at the circadian performance curve nadir. If manning could be increased, controllers could rotate naps on the night-shift and/or more days could be given off between cycles to compensate for sleep deficits. These strategies are used in some civilian air traffic control operations[11].

Areas For Further Study

Several issues need to be investigated more fully before we can, or should, proceed with some of these interventions. A definitive study of USAF ATC night-shift performance should be performed. Shift-specific rates should be determined for ATC related mishaps recorded in the NTSB and USAF Safety Center databases. A cross-sectional study of all USAF ATCs would be useful for demographic information. This would also shed light on the representativeness of our sample and its referability to the larger ATC population. A retrospective study looking for desynchronosis related symptoms among three matched groups of present ATC shiftworkers, former ATC shiftworkers, and dayworkers would be of some benefit in the context of chronic health effects. A study of the nutrition and exercise of U.S. Air Force rapid rotators versus U.S. Air Force dayworkers would be useful in the planning for improvements in these areas. A comparison of performance, sleep, and social adjustment between forward rapid shift rotations and backward rapid shift rotations would be interesting. The forward rotating USAF ATCs and the backward rotating FAA ATCs provide two inviting groups for study although disparate demographic profiles would complicate the comparison. A study of the impact of sustained low-workload levels on ATC proficiency over successive days would shed light on ATC concerns in this area.

CONCLUSIONS

USAF ATCs on a forward rapid rotation shift may be impaired on the night-shift. They maintained diurnally oriented circadian rhythms as evidenced through monitoring of their oral temperature rhythms. While operating on the night-shift at the nadir of their circadian rhythms they reported increased sleep, confusion, fatigue, and decreased vigor; they also slept more as scored by objective measures and had lower general activity levels. RAPCON ATCs reported more confusion and less vigor than tower ATCs but the reasons for this are unclear. The sleep following the swing-shift was significantly longer than that obtained following the day-shift. The potential impact of this apparent impairment on ATC night-shift duty performance and air traffic safety should be evaluated.

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